Evidence of chaotic dynamics in plasma density fluctuations in tokamak TCABR

Crepaldi, C.[1]*, Guimarães-Filho, Z. O.[1]

[1]Institute of Physics of the University of São Paulo, *e-mail: crepaldi@if.usp.br

1st Perspectives on Oscillation Control

Introduction

One of the ways to achieve nuclear fusion is by using magnetic fields to confine hot ionized plasma. However, the road to controlled fusion is steep, and one of the many problems to be solved is keeping hot and dense plasma confined for long enough time, so that the nuclear fusion reactions can start.

Among others, a factor that compromises the quality of the confinement of magnetically confined plasma is the anomalous transport of particles attributed to the electrostatic turbulence observed at the edge region of the plasma. There is no consensus yet about the dynamical nature of these fluctuations, and it is possible to find in the literature models that treat it as chaotic or stochastic.

A recently published (2007) method that proposes to distinguish the dynamical nature of fluctuations in time series is the Complexity-Entropy Diagram [1-2], a method that has recently been used in several areas, among them Plasma Physics.

In this work, we will address the problem of analyzing the dynamical nature of plasma turbulence at the plasma edge of tokamak TCABR using signals obtained by the Langmuir probe diagnostic and compare it to published results of similar studies [3-4] done in other tokamaks using signals from different diagnostics.

Methodology

The C-H Diagram method starts by finding the ordinal state (**π**) of each d-point sub-series of our time-series. This state can be defined as the permutation that puts the sub-series in ascending or descending order. Then we must compute the probability of finding a sub-series in each of the d! possible ordinal states.

Be a time-series **F = {f_t for t=1,2,3,…,M}**, the set of all N=M-d+1 sub-series of **F** is defined as **X = {(f_j,…,f_{j+d-1}) : f_j ∈ F for j=1,…,N}**. Using a relative frequency as an approximation for the probability, we can compute the prob. distribution as

$$p_\pi = \frac{\#\{x : x \in X, x \text{ has type } \pi\}}{N}$$

Finally, we can use that distribution to compute the Jensen-Shannon Complexity (**C_{JS}=C(p)**) and Normalized Shannon Entropy (**H_S=H(p)**).

The region of the diagram in which the C-H plane image of the time-series falls tells us its predominant dynamical nature.

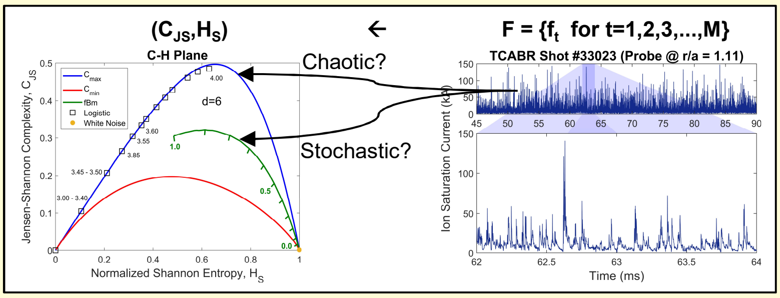

Figure 1 – Methodology graphical abstract. All summarizes to computing the complexity and entropy of a time series using the ordinal state probability distribution and interpreting its relative position in the C-H Diagram.

Results

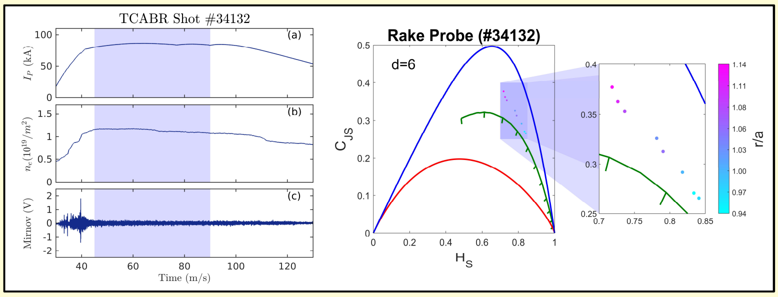

Figure 2 – **Left:** Plasma conditions of a common shot. (a) Plasma current, (b) Electron density, (c) Mirnov coil potential. Highlighted is the analyzed interval. **Right:** C-H Diagram with a single shot analyzed.

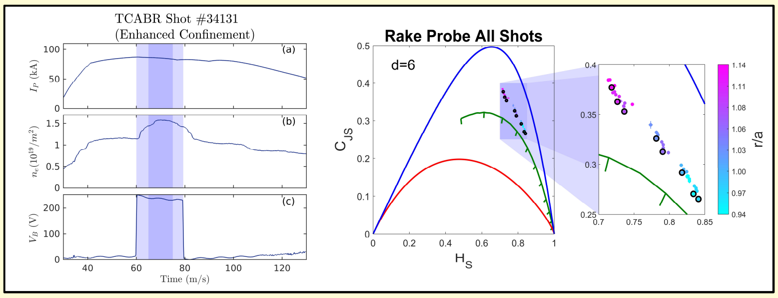

Figure 3 – **Left:** Plasma conditions of a confinement-enhanced shot. (a) Plasma current, (b) Electron density, (c) Electrode bias. Highlighted is the electrode-active interval and the analyzed interval (darker shade). **Right:** C-H Diagram with 5+1 shots analyzed. The "+1" is the common shot of Fig. 2 added here for quick comparison (highlighted points).

Conclusions

- ✓ As shown by Figs. 2-3, our results show us that the position of the ion saturation current signals in the C-H plane corresponds to the **Chaotic Region,** the region above the fBm curve (green line).
  - ✓ Agrees qualitatively with those obtained in other tokamaks with different diagnostics [3-4].
- ✓ There seems to be dependence between the probe radial position and the time-series image in the C-H plane.
- ✓ Surprisingly, the electrode effect in the confinement-enhanced shots **does not** affect significantly the position in the C-H plane.
  - ✓ It would be expected that the electrode action, which breaks the convective structures, would decrease the convective transport, shifting the time-series image to a more stochastic region of the diagram.

References

[1] BANDT, C. and POMPE, B. Permutation Entropy: A Natural Complexity Measure for Time Series. Physical Review Letters 88 (2002) 174102.

[2] ROSSO, O. et al. Distinguishing noise from chaos. Physical Review Letters 99 (2007) 154102.

[3] MAGGS, J. E. et al. Chaotic density fluctuations in L-mode plasmas of the DIII-D tokamak. Plasma Physics and Controlled Fusion 57 (2015) 045004.

[4] ZHU, Z. et al. Chaotic edge density fluctuations in the Alcator C-Mod tokamak. Physics of Plasmas 24 (2017) 042301.

Acknowledgments:

FAPESP CNPq